BIOLOGICAL INTEGRITY OF BEAVER CREEK IN THE UPPER MADISON RIVER TMDL PLANNING AREA BASED ON THE STRUCTURE AND COMPOSITION OF THE BENTHIC ALGAE COMMUNITY

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Summary

In August 2002, periphyton samples were collected from 2 sites on Beaver Creek in the upper Madison River TMDL planning area in southwestern Montana for the purpose of assessing whether this stream is water-quality limited and in need of TMDLs. The samples were collected following MDEQ standard operating procedures, processed and analyzed using standard methods for periphyton, and evaluated following modified USEPA rapid bioassessment protocols for wadeable streams.

The sample collected at the upper site on Beaver Creek was dominated by *Hydrurus foetidus*, a macroscopic and gelatinous chrysophyte that is common in unshaded mountain streams in North America. In addition to ample sunlight, *Hydrurus foetidus* requires cold temperatures (<10°C) and low (circumneutral) pH. *Hydrurus foetidus* was absent from the sample collected at the lower site on Beaver Creek.

Diatoms were frequent in both samples collected from Beaver Creek and the diatom associations at both sites were dominated by species that are either sensitive to organic pollution or only somewhat tolerant of organic pollution. Values for the pollution index and siltation index indicate no impairment from organic loading or sedimentation, respectively. Slightly depressed diversity values and slightly elevated values for percent dominant species, disturbance index, and percent abnormal cells indicate that the periphyton community was subjected to minor stresses. However, these stresses were probably natural in origin and caused by low water temperatures and low nutrient concentrations coupled with rapidly growing diatom populations.

The two sites shared 68% of their diatom associations, which indicates that there was little or no difference between them in terms of floristics or ecological conditions. The major distinction between the two sites appears to be the greater exposure to sunlight at the upstream site, which allowed for optimum growth of *Hydrurus foetidus.*

Introduction

This report evaluates the biological integrity[1], support of aquatic life uses, and probable causes of stress or impairment to aquatic communities in Beaver Creek in the upper Madison River TMDL planning area in southwestern Montana. The purpose of this report is to provide information that will help the State of Montana determine whether Beaver Creek is water-quality limited and in need of TMDLs.

The federal Clean Water Act directs states to develop water pollution control plans (Total Maximum Daily Loads or TMDLs) that set limits on pollution loading to water-quality limited waters. Water-quality limited waters are lakes and stream segments that do not meet water-quality standards, that is, that do not fully support their beneficial uses. The Clean Water Act and USEPA regulations require each state to (1) identify waters that are water-quality limited, (2) prioritize and target waters for TMDLs, and (3) develop TMDL plans to attain and maintain water-quality standards for all water-quality limited waters.

Evaluation of aquatic life use support in this report is based on the species composition and structure of periphyton (aka benthic algae, phytobenthos) communities at two sites that were sampled in August of 2002. Periphyton is a diverse assortment of simple photosynthetic organisms called algae that live attached to or in close proximity of the stream bottom. Some algae form long filaments or large colonies and are conspicuous to the unaided eye. But most algae, including the ubiquitous diatoms, can be seen and identified only with the aid of a microscope. The periphyton community is a basic biological component of all aquatic ecosystems. Periphyton accounts for much of the primary production and biological diversity in Montana streams (Bahls et al. 1992). Plafkin et al. (1989) and Barbour et al. (1999) list several advantages of using periphyton in biological assessments.

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[1] *Biological integrity* is defined as "the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region" (Karr and Dudley 1981).

Project Area and Sampling Sites

The project area is located within subregion 17g of the Middle Rockies Ecoregion in Gallatin County, Montana. This is a partially glaciated subregion of carbonate-rich, mostly forested mountains and hills with some lakes and springs (Woods et al. 1999). Bedrock and surface material is composed mostly of faulted and folded Mesozoic-Paleozoic sedimentary rocks, including limestone, and Quaternary drift and colluvium. Vegetation is mainly mixed conifer forest of Douglas-fir and subalpine fir, with alpine tundra on the highest peaks. The main land uses are logging, mining, recreation, livestock grazing, and wildlife habitat.

Periphyton samples were collected at two sites on Beaver Creek (Map 1 and Table 1). Beaver Creek is in the Madison River hydrologic unit (USGS HUC 10020007). The Madison River, along with the Jefferson and Gallatin Rivers, are the three main tributaries of the Missouri River. Beaver Creek is classified B-1 in the Montana Surface Water Quality Standards.

Methods

Periphyton samples were collected following standard operating procedures of the MDEQ Planning, Prevention, and Assistance Division. Using appropriate tools, microalgae were scraped, brushed, or sucked from natural substrates in proportion to the importance of those substrates at each study site. Macroalgae were picked by hand in proportion to their abundance at the site. All collections of microalgae and macroalgae were pooled into a common container and preserved with Lugol's (IKI) solution.

The samples were examined to estimate the relative abundance and rank by biovolume of diatoms and genera of soft (non-diatom) algae according to the method described in Bahls (1993). Soft algae were identified using Smith (1950), Prescott (1962, 1978), John et al. (2002), and Wehr and Sheath (2003). These books also served as references on the ecology of the soft algae, along with Palmer (1969, 1977).

After the identification of soft algae, the raw periphyton samples were cleaned of organic matter using sulfuric acid, potassium dichromate, and hydrogen peroxide. Then permanent diatom slides were prepared using Naphrax, a high refractive index mounting medium, following *Standard Methods for the Examination of Water and Wastewater* (APHA 1998). At least 400 diatom cells (800 valves) were counted at random and identified to species. The following were the main taxonomic references for the diatoms: Krammer and Lange-Bertalot 1986, 1988, 1991a, 1991b; Lange-Bertalot 1993, 2001; Krammer 1997a, 1997b, 2002; Reichardt 1997, 1999. Diatom naming conventions followed those adopted by the Academy of Natural Sciences for USGS NAWQA samples (Morales and Potapova 2000) as updated in 2003 (Dr. Eduardo Morales, Academy of Natural Sciences, digital communication). Van Dam et al. (1994) was the main ecological reference for the diatoms.

The diatom proportional counts were used to generate an array of diatom association metrics. A metric is a characteristic of the biota that changes in some predictable way with increased human influence (Barbour et al. 1999). Diatoms are particularly useful in generating metrics because there is a wealth of information available in the literature regarding the pollution tolerances and water quality preferences of common diatom species (e.g., Lowe 1974, Beaver 1981, Lange-Bertalot 1996, Van Dam et al. 1994).

Values for selected metrics were compared to biocriteria (numeric thresholds) developed for streams in the Rocky Mountain ecoregions of Montana (Table 2). These criteria are based on metric values measured in least-impaired reference streams (Bahls et al. 1992) and metric values measured in streams that are known to be impaired by various sources and causes of pollution (Bahls 1993). The criteria in Table 2 are valid only for samples collected during the summer field season (June 21-September 21) and distinguish among four levels of stress or impairment and three levels of aquatic life use support: (1) no impairment or only minor impairment (full support); (2) moderate impairment (partial support); and (3) severe impairment (nonsupport). These impairment levels correspond to excellent, good, fair, and poor biological integrity, respectively. In cold, high-gradient mountain streams, natural stressors will often mimic the effects of man-caused impairment on some metric values.

Quality Assurance

Several steps were taken to assure that the study results are accurate and reproducible. Upon receipt of the samples, station and sample attribute data were recorded in the Montana Diatom Database and the samples were assigned a unique number, e.g., 2653-01. The first part of this number (2653) designates the sampling site (Beaver Creek below Hilgard Creek) and the second part (01) designates the number of periphyton samples that that have been collected at this site for which data have been entered into the Montana Diatom Database.

Sample observations and analyses of soft (non-diatom) algae were recorded in a lab notebook along with information on the sample label. A portion of the raw sample was used to make duplicate diatom slides. The slide used for the diatom proportional count will be deposited in the Montana Diatom Collection at the University of Montana Herbarium in Missoula. The duplicate slide will be retained by *Hannaea* in Helena. Diatom proportional counts have been entered into the Montana Diatom Database.

Results and Discussion

Results are presented in Tables 3, 4 and 5, which are located near the end of this report following the references section. Copies of aquatic plant field sheets are included in Appendix A. Appendix B contains a diatom report for each sample. Each diatom report includes an alphabetical list of diatom species in that sample and their percent abundances, and values for 65 different diatom metrics and ecological attributes.

Sample Notes

Beaver Creek below Hilgard Creek. This sample consisted of a 50 ml centrifuge tube packed with *Hydrurus foetidus* and mud. The sample was extremely silty.

Beaver Creek at Highway 287. This sample was sparse and consisted mostly of a small wad of terrestrial plant roots.

Non-Diatom Algae (Table 3)

Beaver Creek below Hilgard Creek. The sample from this site was dominated by *Hydrurus foetidus*:

> One of the most dramatic examples of a cold-water stenotherm is the mountain-stream-dwelling chrysophyte *Hydrurus foetidus*. This macroscopic, brown, gelatinous, unpleasant-smelling alga is relatively abundant in both the eastern and western mountain streams of North America. The gelatinous envelope in which the cells are embedded is exceedingly tough and the plant frequently covers the entire surface of submerged rocks and has caused more than one hiker to lose his or her footing when crossing a stream. It normally begins to disappear when water temperatures rise much above 10°C...Other requirements for this species apparently include low pH and bright sunlight (Wehr and Sheath 2003).

Diatoms were frequent in this sample and *Hannaea arcus* was the dominant diatom from a visual standpoint.

Beaver Creek at Highway 287. Diatoms were also frequent in this sample and ranked first in biovolume. The filamentous green alga *Ulothrix* ranked second in biovolume, but only occasional cells of this genus were observed. *Ulothrix* generally prefers cool, well-aerated waters. *Closterium*, a desmid, ranked third and *Oscillatoria*, a filamentous cyanobacterium, ranked fourth in biovolume. Both of these algae were represented by only occasional cells. *Hydrurus foetidus* was absent from the sample collected at this site.

Diatoms (Table 4)

All six of the major diatom species from Beaver Creek are included in pollution tolerance classes 3 or 2 and are either sensitive to organic pollution or only somewhat tolerant of organic pollution (Table 4). None of the major diatom species are most tolerant of organic pollution (pollution tolerance class = 1).

Some, if not all, of the stresses indicated at the two sites appear to be natural in origin. High values for the disturbance index and percent dominant species and low values for the diversity index indicate minor stress related to steep gradients, fast currents, cold temperatures, and low nutrient concentrations. Acceptable values for the pollution index and low values for the siltation index indicate that organic enrichment and sedimentation did not have a significant effect on the benthic algae at these sites. The two sites on Beaver Creek shared 68% of their diatom associations (Table 4), indicating that they were virtually identical and that there was no significant floristic or ecological difference between them.

Beaver Creek below Hilgard Creek. Aside from minor natural stresses recorded at this site, three teratological cells of *Cocconeis placentula* were observed during the diatom proportional count. Abnormal diatom cells sometimes indicate elevated concentrations of heavy metals (McFarland et al. 1997). However, there are many other possible causes of abnormal diatom cells, including natural factors such as rapid population growth and crowding, silica depletion, low water temperatures, and low pH. The araphid and monoraphid diatoms, which include *Cocconeis placentula*, seem to be especially prone to producing teratological cells. Given these circumstances, the minor stress indicated by abnormal cells at the upper site on Beaver Creek is probably natural in origin.

Beaver Creek at Highway 287. Aside from minor stresses recorded here, six abnormal cells of *Achnanthidium minutissimum, Cocconeis placentula, Encyonema silesiacum,* and *Hannaea arcus* were observed during the diatom proportional count. Three of these four species are either araphid or monoraphid diatoms and were major species in this sample, which indicates that they comprised rapidly expanding populations that may have been prone to producing abnormal cells. Given these circumstances, the minor stress indicated by abnormal cells at the lower site on Beaver Creek is also probably natural in origin.

Modal Categories (Table 5)

Several ecological attributes assigned by Stevenson and Van Dam et al. (1994) were selected from the diatom reports in the appendix and modal categories of these attributes were extracted to characterize water quality tendencies in Beaver Creek (Table 5). Most of the diatom species at both sites were not motile, indicating that they were not adapted to withstanding high loads of sediment or aggrading substrates. Most diatoms at both sites indicated circumneutral (pH ~7) and fresh-brackish (TDS <900 mg/L) waters. The majority of diatoms at both sites are autotrophs, meaning that they require inorganic nitrogen for their nutrition but they also tolerate elevated concentrations of organically-bound nitrogen. Most diatoms at the upper site were not classified with regard to their oxygen requirements, but the majority of diatoms at the lower site require close to 100% saturation of dissolved oxygen. Most diatoms at the upper site were unclassified with regard to saprobity, but most diatoms at the lower site indicate 70-85% oxygen saturation and BOD levels of 2-4 mg/L. The majority of diatoms at both sites tolerate a wide range of trophic conditions ranging from oligotrophic to eutrophic (Van Dam et al. 1994).

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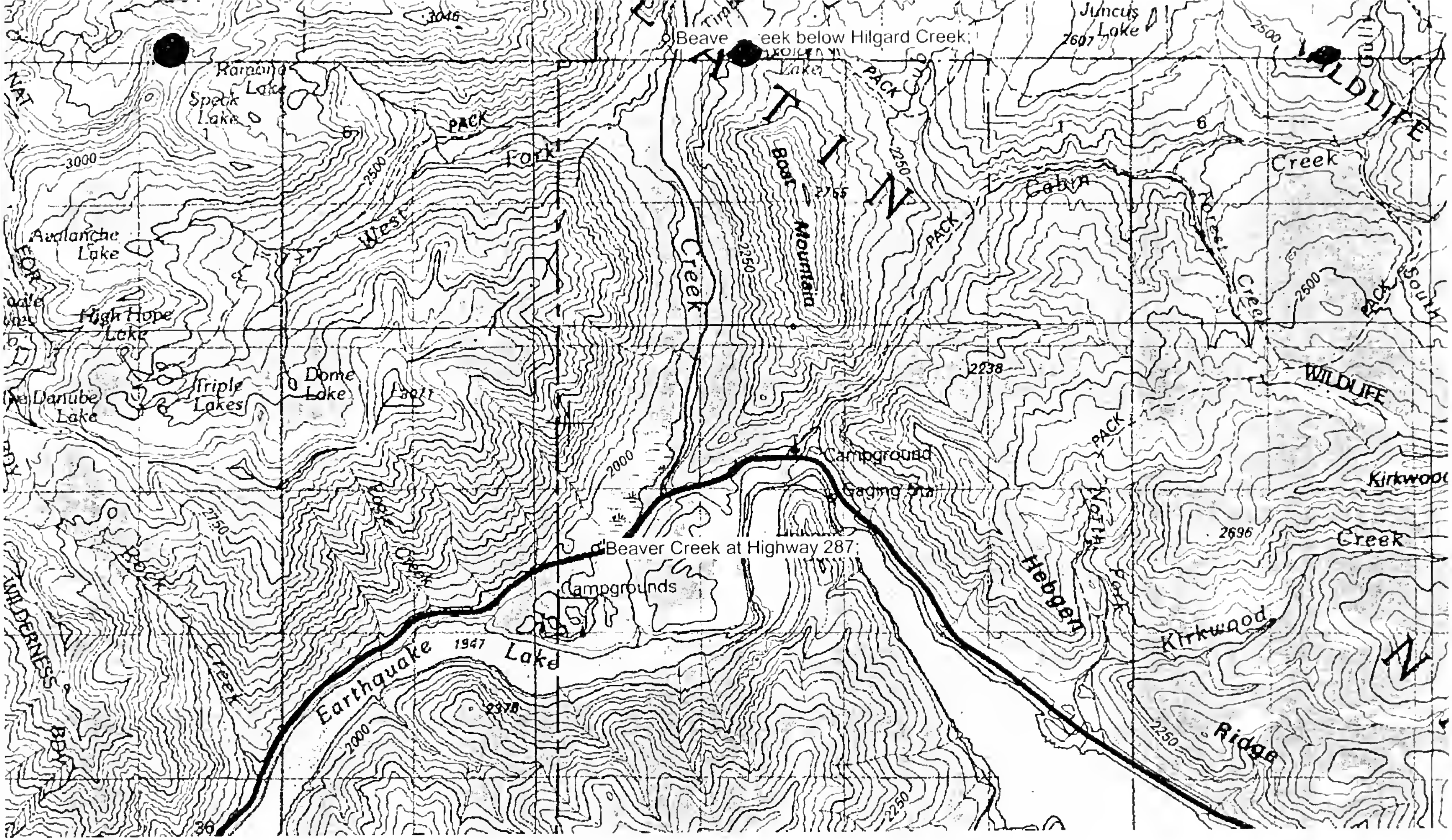

Map 1. Location of periphyton sampling stations on Beaver Creek.

'Hebgen Lake 100K; MT,ID,WY'; Scale: 1" = 0.953Mi 1,534Mt 5,031Ft, 1 Mi = 1.049" , 1 cm = 604Mt

Table 1. Location of periphyton sampling stations in the upper Madison River TMDL planning area, 2002.

Station	MDEQ Station Code	*Hannaea* Sample Number	Latitude	Longitude	Sample Date
Beaver Creek below Hilgard Creek	M06BEAVC01	2653-01	44-54-51	111-21-40	8/20/02
Beaver Creek at Highway 287	M06BEAVC02	2654-01	44-51-45	111-22-16	8/22/02

Table 2. Diatom association metrics used by the State of Montana to evaluate biological integrity in mountain streams: references, range of values, expected response to increasing impairment or natural stress, and criteria for rating levels of biological integrity. The lowest rating for any one metric is the rating for that site.

Biological Integrity/ Impairment or Stress/ Use Support	No. of Species Counted[1]	Diversity Index[2] (Shannon)	Pollution Index[3]	Siltation Index[4]	Disturbance Index[5]	% Dominant Species[6]	% Abnormal Cells[7]
Excellent/None Full Support	>29	>2.99	>2.50	<20.0	<25.0	<25.0	0
Good/Minor Full Support	20-29	2.00-2.99	2.01-2.50	20.0-39.9	25.0-49.9	25.0-49.9	>0.0, <3.0
Fair/Moderate Partial Support	19-10	1.00-1.99	1.50-2.00	40.0-59.9	50.0-74.9	50.0-74.9	3.0-9.9
Poor/Severe Nonsupport	<10	<1.00	<1.50	>59.9	>74.9	>74.9	>9.9
References	Bahls 1979 Bahls 1993	Bahls 1979	Bahls 1993	Bahls 1993	Barbour et al. 1999	Barbour et al. 1999	McFarland et al. 1997
Range of Values	0-100+	0.00-5.00+	1.00-3.00	0.0-90.0+	0.0-100.0	~5.0-100.0	0.0-30.0+
Expected Response	Decrease[8]	Decrease[8]	Decrease	Increase	Increase	Increase	Increase

[1]Based on a proportional count of 400 cells (800 valves)
[2]Base 2 [bits] (Weber 1973)
[3]Composite numeric expression of the pollution tolerances assigned by Lange-Bertalot (1979) to the common diatom species
[4]Sum of the percent abundances of all species in the genera *Navicula, Nitzschia* and *Surirella*
[5]Percent abundance of Achnanthidium minutissimum (synonym: *Achnanthes minutissima*)
[6]Percent abundance of the species with the largest number of cells in the proportional count
[7]Cells with an irregular outline or with abnormal ornamentation, or both
[8]Species richness and diversity may increase somewhat in mountain streams in response to slight to moderate increases in nutrients or sediment

Table 3. Relative abundance of cells and ordinal rank by biovolume of diatoms (Division Bacillariophyta) and genera of non-diatom algae in peripnyton samples collected from Beaver Creek in 2002.

Taxa	Beaver Creek below Hilgard Creek M06BEAVC01	Beaver Creek at Highway 287 M06BEAVC02
Cyanophyta		
Oscillatoria		occasional/4th
Chlorophyta		
Closterium		occasional/3rd
Ulothrix		occasional/2nd
Chrysophyta		
Hydrurus foetidus	dominant/1st	
Bacillariophyta	frequent/2nd	frequent/1st
# Non-Diatom Genera	1	3

Table 4. Percent abundance of major diatom species[1] and values of selected diatom association metrics for periphyton samples collected from Beaver Creek in 2002. Underlined values indicate minor stress; **bold values** indicate moderate stress; **underlined and bold** values indicate severe stress; all other values indicate no stress and full support of aquatic life uses when compared to criteria for mountain streams in Table 2. Stress may be natural or anthropogenic (see text)

Species/Metric	PTC[2]	Beaver Creek Below Hilgard Creek	Beaver Creek at Highway 287
Achnanthidium minutissimum	3	20.65	27.53
Encyonema silesiacum	2	23.41	27.30
Fragilaria vaucheriae	2	3.96	3.34
Hannaea arcus	3	33.13	8.06
Reimeria sinuata	3	2.52	4.95
Staurosira construens	3	0.96	8.18
Number of Species Counted		30	42
Shannon Species Diversity		2.88	3.42
Pollution Index		2.64	2.59
Siltation Index		4.80	4.95
Disturbance Index		20.65	27.53
Percent Dominant Species		33.13	27.53
Percent Abnormal Cells		0.36	0.69
Similarity Index[3]			68.00

[1]A major diatom species accounts for 3.0% or more of the cells at one or more stations in a sample set.
[2](Organic) Pollution Tolerance Class (Lange-Bertalot 1979): 1 = most tolerant; 2 = tolerant; 3 = sensitive.
[3]Percent Community Similarity (Whittaker 1952) when compared to the diatom assemblage at the adjacent upstream station

Table 5. Modal categories for selected ecological attributes of diatom species in Beaver Creek.

Ecological Attribute	Beaver Creek below Hilgard Creek M06BEAVC01	Beaver Creek at Highway 287 M06BEAVC02
Motility[1]	Not Motile	Not Motile
pH[2]	Circumneutral	Circumneutral
Salinity[2]	Fresh-Brackish	Fresh-Brackish
Nitrogen Uptake[2]	Autotrophs (tolerate high organics)	Autotrophs (tolerate high organics)
Oxygen Demand[2]	Not Classified	Continuously High
Saprobity[2]	Not Classified	beta-Mesosaprobous
Trophic State[2]	Variable	Variable

[1]Dr. R. Jan Stevenson, Michigan State University, digital communication.
[2]Van Dam et al. 1994